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APPLICATION NUMBER: ***60/546,848***
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PROVISIONAL APPLICATION FOR PATENT COVER SHEET

This is a request for filing a PROVISIONAL APPLICATION FOR PATENT under 37 CFR 1.53(c).

Express Mail Label No. EV 073381591 US

INVENTOR(S)		
Given Name (first and middle [if any])	Family Name or Surname	Residence (City and either State or Foreign Country)
HUI	WANG	FREMONT, CALIFORNIA

Additional inventors are being named on the ____ *separately numbered sheets attached hereto*

TITLE OF THE INVENTION (500 characters max)

METHODS FOR REDUCING RESIDUALS DURING ELECTROPOLISHING

Direct all correspondence to: **CORRESPONDENCE ADDRESS**

☐ Customer Number:

OR

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ENCLOSED APPLICATION PARTS *(check all that apply)*

☑ Specification *Number of Pages* 6

☐ CD(s), Number ____

☑ Drawing(s) *Number of Sheets* 12

☑ Other (specify) RETURN RECEIPT POSTCARD

☑ Application Data Sheet. See 37 CFR 1.76

METHOD OF PAYMENT OF FILING FEES FOR THIS PROVISIONAL APPLICATION FOR PATENT

☑ Applicant claims small entity status. See 37 CFR 1.27.

☑ A check or money order is enclosed to cover the filing fees.

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FILING FEE Amount ($)

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The invention was made by an agency of the United States Government or under a contract with an agency of the United States Government.

☑ No.

☐ Yes, the name of the U.S. Government agency and the Government contract number are: ____

Respectfully submitted,

SIGNATURE ____

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Date FEBRUARY 23, 2004

REGISTRATION NO. ____
(if appropriate)
Docket Number: ____

USE ONLY FOR FILING A PROVISIONAL APPLICATION FOR PATENT

METHODS FOR REDUCING RESIDUALS DURING ELECTROPOLISHING

INTRODUCTION

The present invention relates generally to a method for reducing or eliminating residual on wafer with minimum dishing during electropolishing metal layers on semiconductor wafers.

SUMMARY OF INVENTION

One aspect of the present invention relates to a method of tuning the removal rate profile to match the un-polished (incoming) metal thickness profile across wafer by varying lateral moving speed between wafer and the polishing nozzle.

In accordance with another aspect of the present invention, a two-step removal process is used to reduce or eliminate residual of metal (Cu) with minimum dishing value. The first step is to arrange nozzle position to center of wafer, then flow electrolyte and apply electrical power. The second step is to move nozzle gradually away from the center of wafer and towards the edge of wafer with flowing electrolyte and applying electrical power.

DETAILED DESCRIPTION OF EXEMPLARY EMBODIMENTS

In order to provide a more thorough understanding of the present invention, the following description sets forth numerous specific details, such as a specific material, parameters, and the like. Additionally, the subject matter of the present invention is particularly suited for use in connection with electroplating and/or electropolishing of semiconductor workpieces or wafers. As a result, exemplary embodiments of the present invention are described in that context. It should be recognized, however, that such description is not intended as a limitation on the scope, the use or applicability of the present invention, but is instead provided to enable a more full and a more complete description of the exemplary embodiments.

Fig. 1 shows an electropolishing mechanism consists of wafer chuck 1002, wafer 1004, moving mechanism to rotate and laterally translate wafer chuck 1002, electrolyte nozzle 1010, moving mechanism 1012 to laterally translate nozzle 1010, and electrical power supply 1018 connecting with wafer 1004 and nozzle anode 1014. For a more detailed description of the electropolisher, see U.S. Letter Patent No. 6,395,152, entitled METHODS AND APPARATUS FOR ELECTROPOLISHING METAL INTERCONNECTIONS ON SEMICONDUCTOR DEVICES, filed on July 2, 1999, the entire content of which is incorporated herein by reference. Also see U.S. Provisional Application Ser. No. 60/462,642, entitled METHODS AND APPARATUS FOR OPTIMIZING ELECTROPOLISHER, filed on April 14, 2003, the entire content of which is incorporated herein by reference, disclosing variety of nozzle shape designs to enhance removal rate profile of nozzle during electrical polishing process.

The removal sequence is shown in Figs. 2A to 2D. Fig. 2A shows an incoming wafer having a metal thickness in the range of 0.5 μm to 3 μm. After performing the first polishing step, the thickness is reduced, as shown in Fig. 2B, to a range between 2000 Å and 3000 Å. Then, the nozzle or wafer moves so that the nozzle is positioned and stopped at the center of wafer. Electrolyte and power are turned on for certain time, creating a post-polished thickness profile as shown in Fig. 2C. The last step is to move nozzle gradually away from the center of wafer and towards the edge of wafer with flowing electrolyte and applying electrical power to remove the remaining Cu to barrier layer as shown in Fig. 2D.

<u>One Step Polishing Process</u>

Figs. 3A to 3D show a transformation of metal thickness profile during a one-step polishing process. Since the relative speed of wafer to nozzle at beginning of electropolishing (center of wafer) is large as previously described in U.S. Letter Patent No. 6,395,152, the polishing profiles generally resemble an upside down trapezoid as shown in Figs. 3A and 3B. When the metal thickness is thin or barrier layer starts to expose as shown in Fig. 3C, the metal film begins to discontinue. When Cu film is discontinued, the polishing current path will be seep through the barrier layer underneath. The barrier metal material is usually Ta, TaN, Ti, TiN, W,

WN, and the resistivity of those metals is usually ten to hundred times higher than that of Cu. Therefore, the polishing rate on discontinued film layer is much lower than that on unbroken or continuous Cu film. The breakage may cause residuals on post-polished metal surface as shown in Figs. 3D and Fig. 3E.

Two Step Polishing Process

Figs. 4A to 4D show a transformation of metal thickness profile during a two-step polishing process. A two-step polishing process includes a center polishing or center touch process. During a center polishing process, the nozzle is positioned at the center of wafer then tuning on electrolyte and electrical current. The remaining metal film profile after the center polishing is similar to the upside down triangle shape as shown in Fig. 4A. The shape of polishing profile after center polishing or center touch process can be adjusted as it is illustrated in Figs. 5A to 5C and described in details below.

After the center polishing process, the second step of the polishing process as previously described in U.S. Letter Patent No. 6,395,152 will be performed. During this second polishing process, barrier layer starts to expose as a point instead of a circle. Therefore, Cu film remains a continuous film layer form during the polishing process as shown in Figs. 4B and 4C. Under this process, the Cu film is polished in a relative high rate and no residual is formed on the post-polished wafer surface, as shown in Fig. 4D.

Fig. 5A shows three center polishing profiles using different polishing currents. Profile 5072 is performed using small polishing current, profile 5070 is performed using a generally medium polishing current, and profile 5074 is performed using a high polishing current. The current range is approximately between 0.05 Amp to 3 Amp. In summary and as shown in Fig. 5A, the small polishing current produces a sharp triangle polishing profile 5072, and the large polishing current produces a relatively flat apex 5074.

Fig. 5B shows two center polishing profiles using different sizes of polishing nozzle with the same polishing current density. Profile 5074 is performed by using a large nozzle and profile

5076 is performed by using a small nozzle. The current density is in the range of 0.5 A/cm^2 to 5 A/cm^2.

Fig. 5C shows a center polishing profile when nozzle is positioned off center of wafer. In this case, the polishing profile resembles more like a trapezoid shape.

<u>Polishing profile tuning by varying lateral relative speed between wafer and nozzle</u>

Fig. 6 shows the polishing profile across wafer by using the standard lateral movement equation as previously described in U.S. Letter Patent No. 6,395,152. However, as shown in Fig. 7, incoming Cu thickness profile of pattern wafer is not uniform or flat. In order to polish away Cu film with minimum dishing and without residual, the polishing profile is tuned to match the incoming Cu thickness profile of wafer.

Fig. 8 shows the average thickness profiles of incoming Cu thickness. Curve 8058 is the average thickness profile of Cu film shown in Fig. 7. More specifically, the values on curve 8058 are the averages of the thickness profiles at any two points with equal radius on the wafer. Due to the pattern sensitivity measured by four-point probe, the thickness profiles generally fluctuated across the entire radius of wafer. In the other word, the thickness variation in short distance is not actual or real and is fluctuated by wire pattern underneath of Cu film. In order to minimize the fluctuation, means of the values from curve 8059 are determined as shown in curve 8060. More specifically, new thickness values represented by curve 8060 are the averages of surrounding thickness points. The number of surrounding points is in the range of 2 to 20, depending on fluctuation. For example, the values on curve 8060 are averages of any 8 surrounding points.

Fig. 9 shows the lateral motion speed compensation curve based on standard removal rate curve shown in Fig. 6 and averaged incoming Cu thickness profile (8060) in Fig. 8. More specifically, the lateral speed compensation factor is calculated by the following formula:

$$X(r) = (Ts(r)/Ta(r))^{\alpha} \qquad (1)$$

Where, the $X(r)$ is lateral speed compensation factor, r is the location nozzle on wafer radius direction, $Ts(r)$ is the standard removal rate, $Ta(r)$ is the averaged thickness as described in Fig. 8, and α is acceleration factor. The acceleration factor α may be in the range of 1 to 2 depending on difference between $Ts(r)$ and $Ta(r)$. More specifically, the greater the difference between $Ts(r)$ and $Ta(r)$, the bigger the acceleration factor is. The actual lateral speed of nozzle or wafer is equal to the speed as previously defined in U.S. Letter Patent No. 6,395,152, and multiplied by lateral speed compensation factor as defined by formula (1).

Fig. 10 shows the curve of averaged thickness and curve of removal rate across wafer after computation of acceleration factor in accordance to formula (1), with an acceleration factor equals to 1.2. Curve 10068 is the averaged Cu thickness curve of income wafer and curve 10066 is the actual removal curve.

Figs. 11A and 11B show an alternative embodiment of the present invention concerning removal curve or profile in two-step polishing process. Fig. 11A shows the removal profile of center polishing or center touch polishing, with polishing current of 0.2 A. Fig. 11B shows the removal profile of a polishing process which uses lateral speed compensation factor based on incoming thickness profile. In order to have uniform removal at the center of wafer, the removal profile in Fig. 11B is reduced at the center of wafer by using either reduced polishing current, to as little as zero current, and/or larger lateral compensation factor.

Various aspects of the present invention disclosed herein can be used in variety of electropolishing mechanisms as shown in Figs. 12A to 12F. In general, both nozzle 12032 and wafer chuck 12020 can be stationary or moveable, and the wafer surface can be face up, or face down, or face side. The following table 1 summary the detail features:

Table 1. Variety of electropolishing mechanism

	Fig. 12A	Fig. 12B	Fig. 12C	Fig. 12D	Fig. 12E	Fig. 12F
Stationary Chuck				Yes	Yes	Yes
Movable Nozzle				Yes	Yes	Yes
Movable Chuck	Yes	Yes	Yes			
Stationary Nozzle	Yes	Yes	Yes			
Chuck Face	Side	Down	Up	Side	Down	Up

Although the exemplary methods and systems used to improve removal rate uniformity during electropolishing have been described with respect to certain embodiments, examples, and applications, it will be apparent to those skilled in the art that various modifications and changes may be made without departing from the invention. For example, the nozzle during center polishing or touch process is taught to be positioned at center of wafer and no movement. The similar results can be achieved by positioning nozzle slightly off the center of wafer and/or moving nozzle/wafer very slowly in lateral direction.

The above detailed description of various devices, methods, and systems is provided to illustrate exemplary embodiments and is not intended to be limiting. It will be apparent to those skilled in the art that numerous modifications and variations within the scope of the present inventions are possible. Therefore, the present invention should not be construed as being limited to the specific forms shown in the drawings and described above.

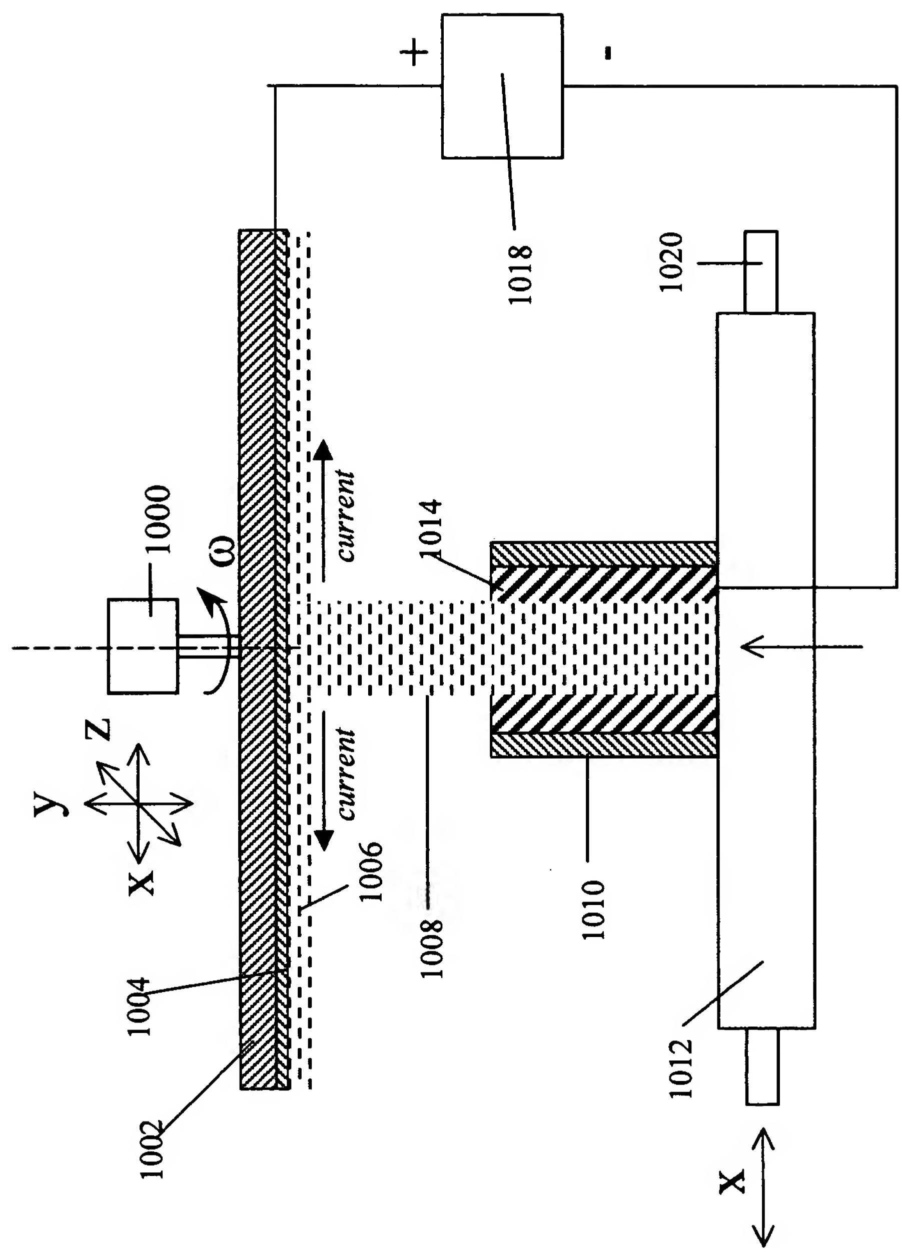

1000
1002
1004
1006
1008
1010
1012
1014
1018
1020
current
current
+
-
ω
x
y
Z
X

Fig. 1

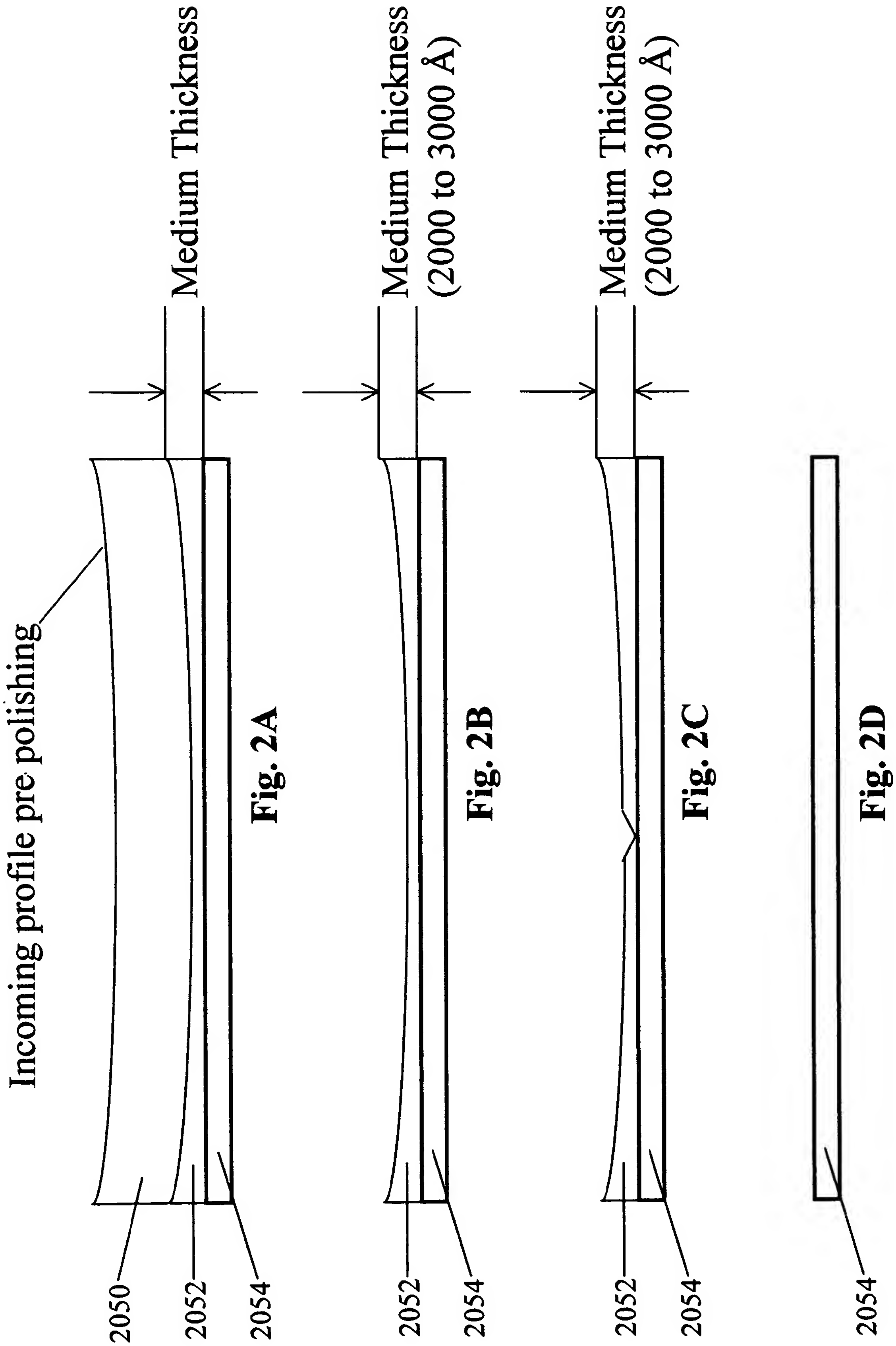


Fig. 2A

Fig. 2B

Fig. 2C

Fig. 2D

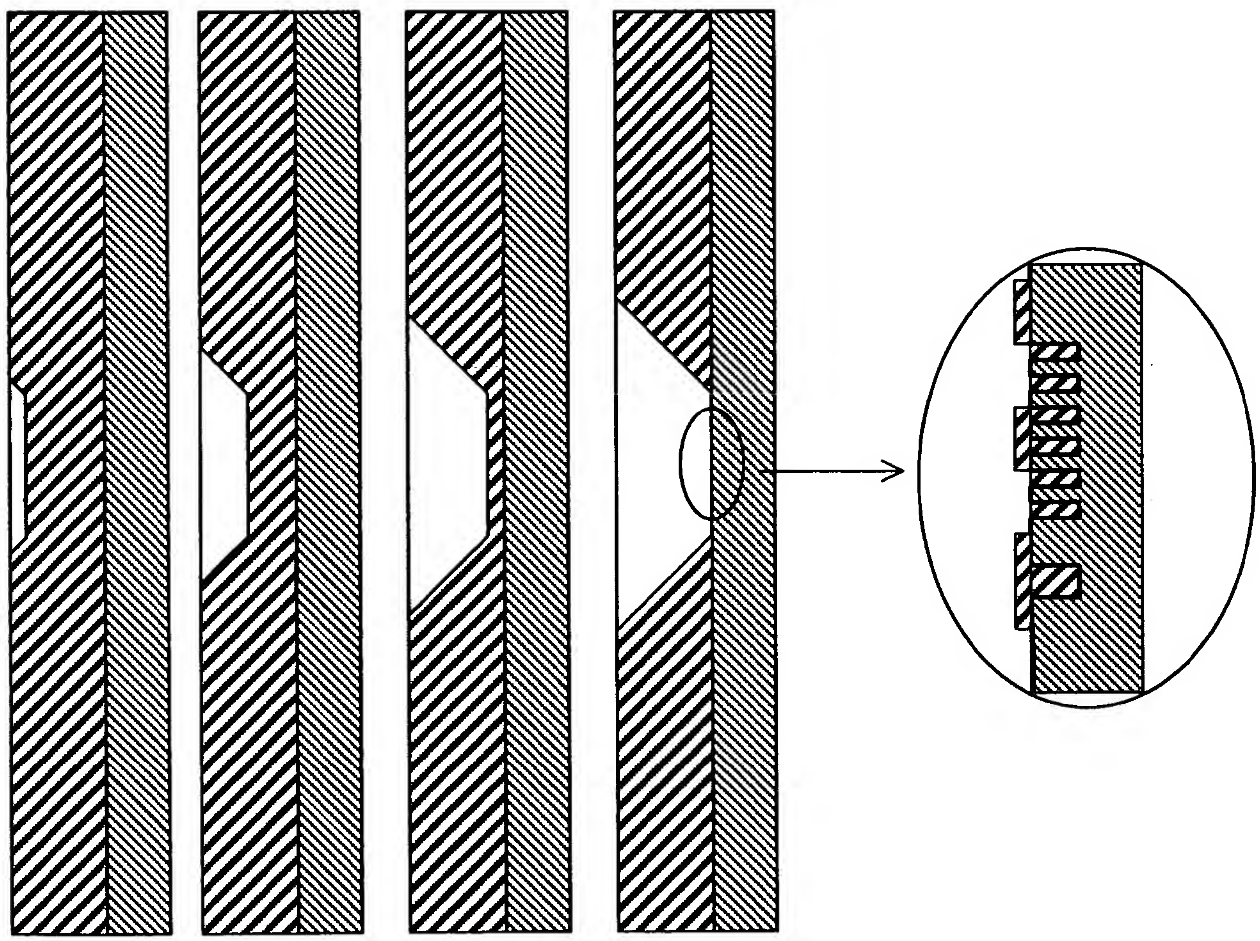
Fig. 3A

Fig. 3B

Fig. 3C

Fig. 3D

Fig. 3E



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Residuals During
Electropolishing
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Filed: Herewith

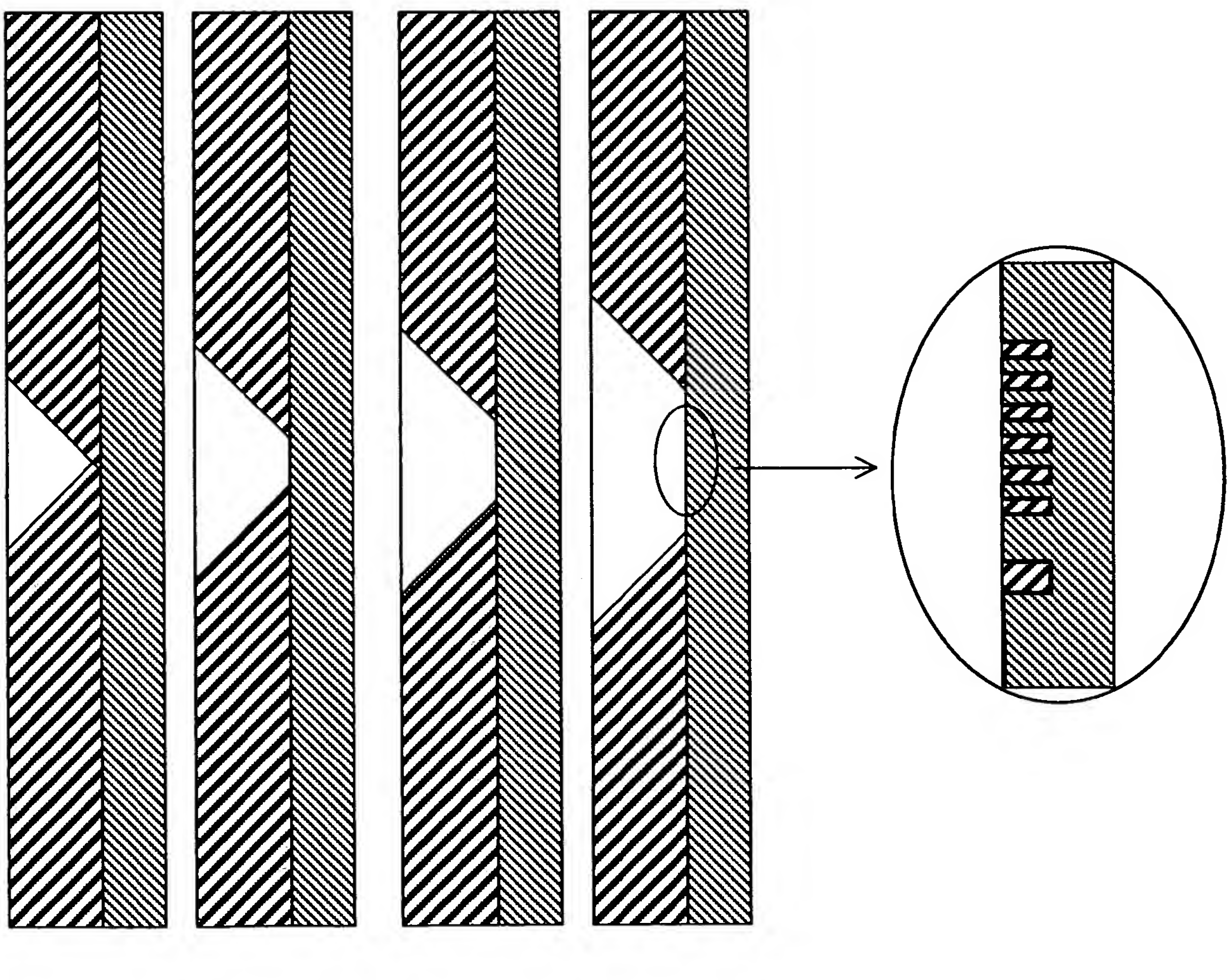
Fig. 4A

Fig. 4B

Fig. 4C

Fig. 4D

Fig. 4E



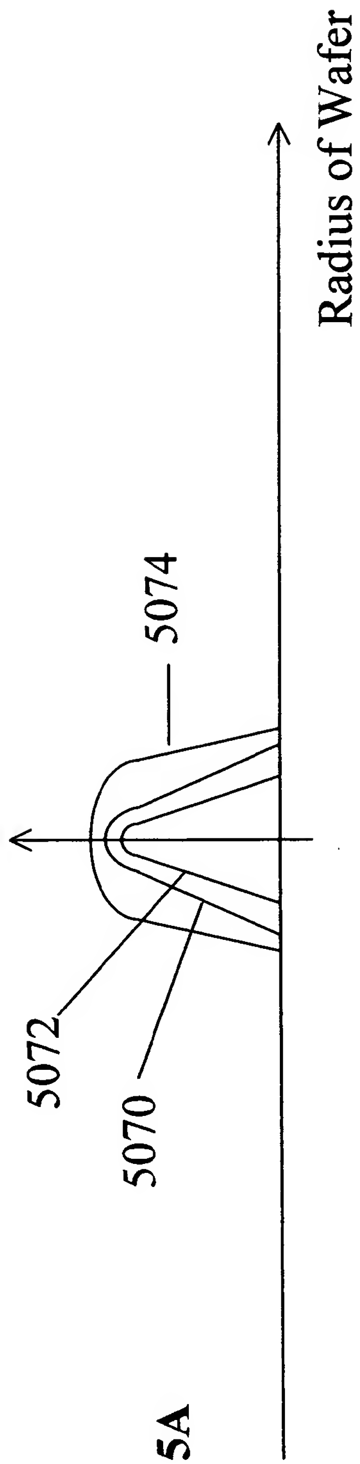


Fig.5A

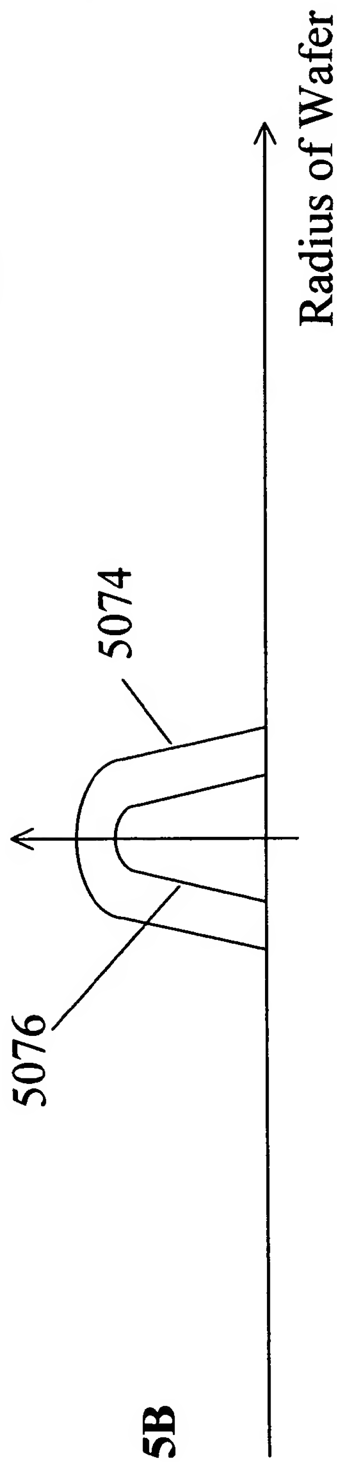


Fig.5B

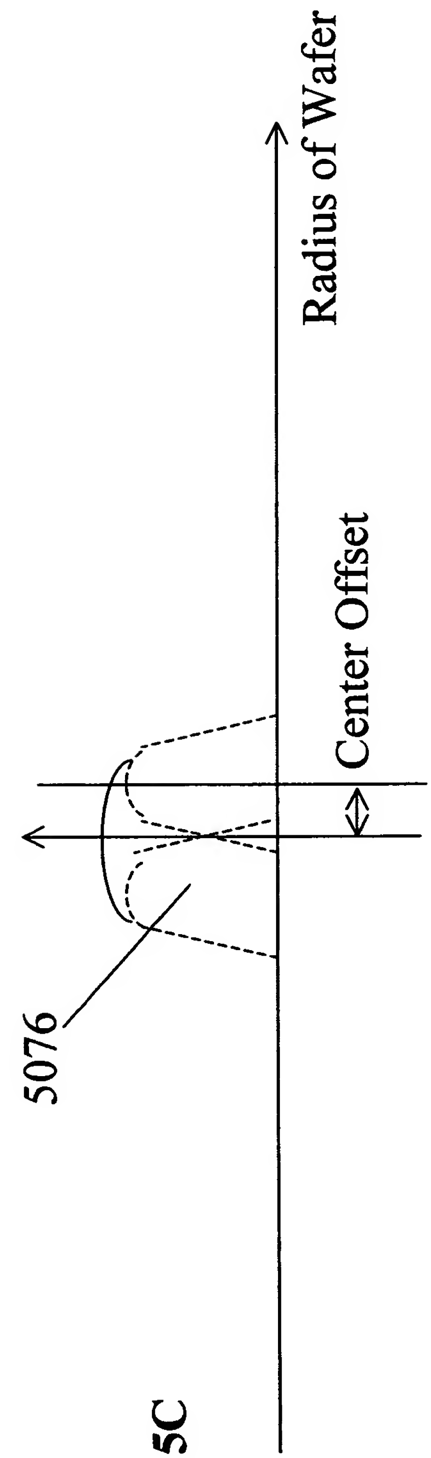


Fig.5C

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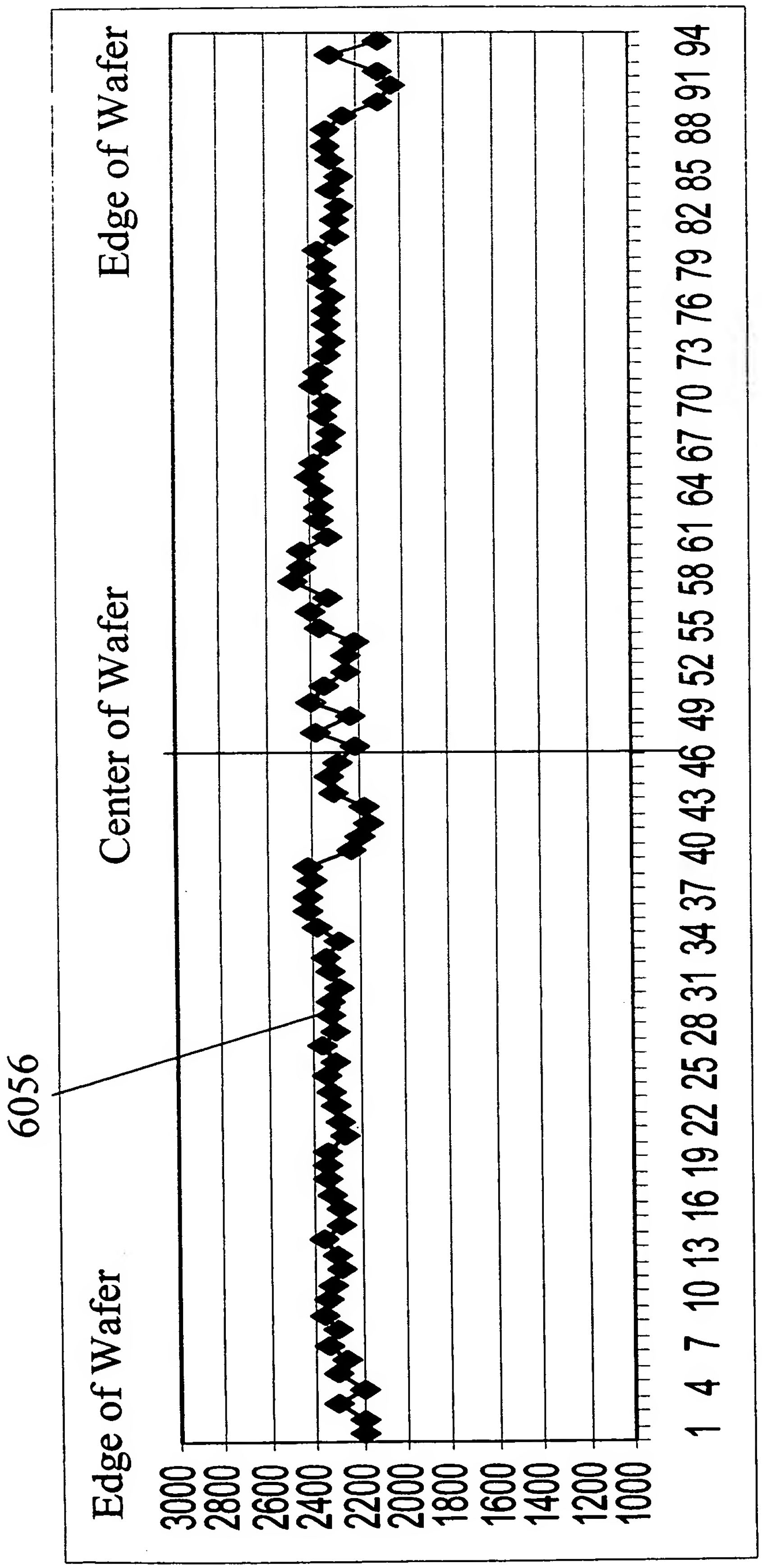

Fig. 6

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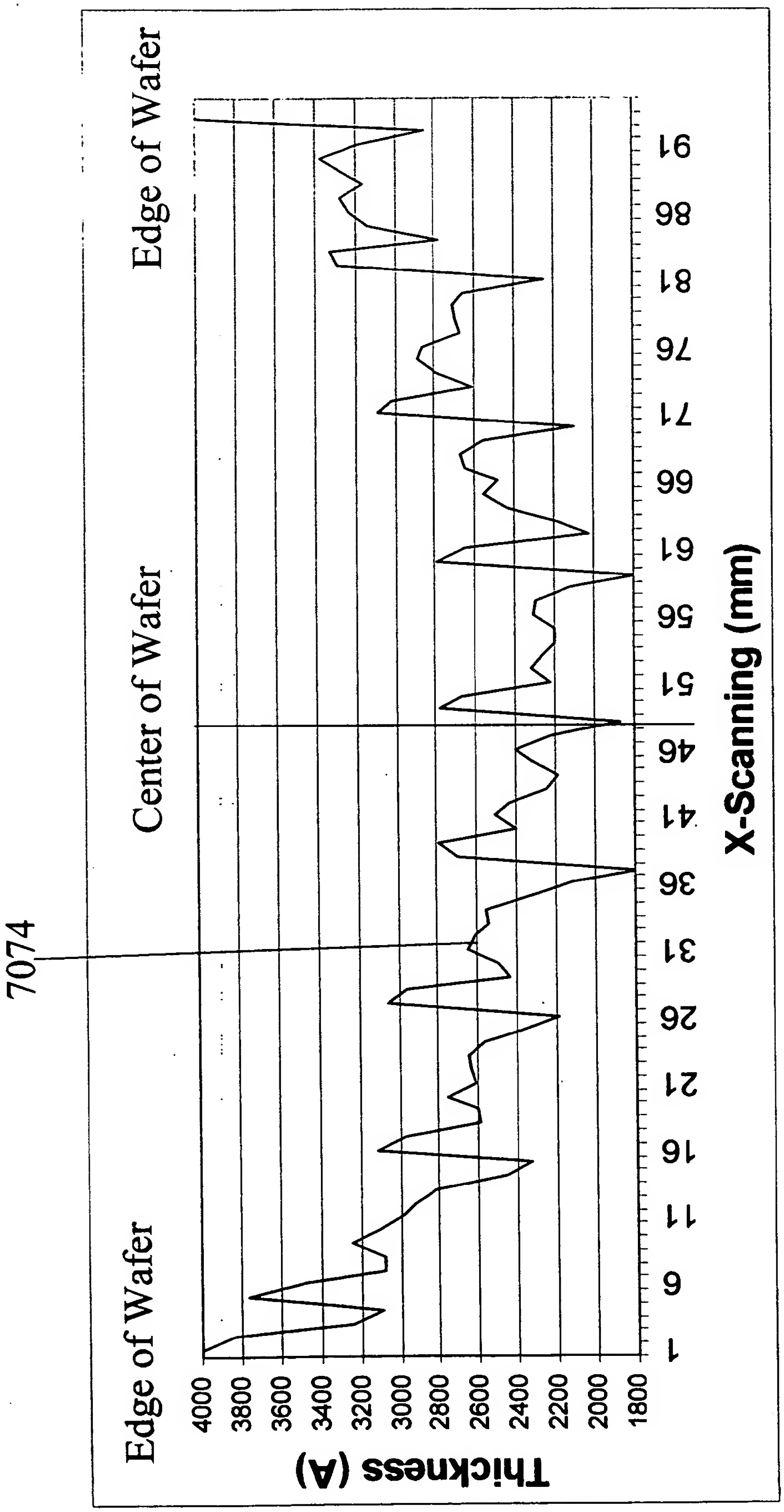

Fig. 7

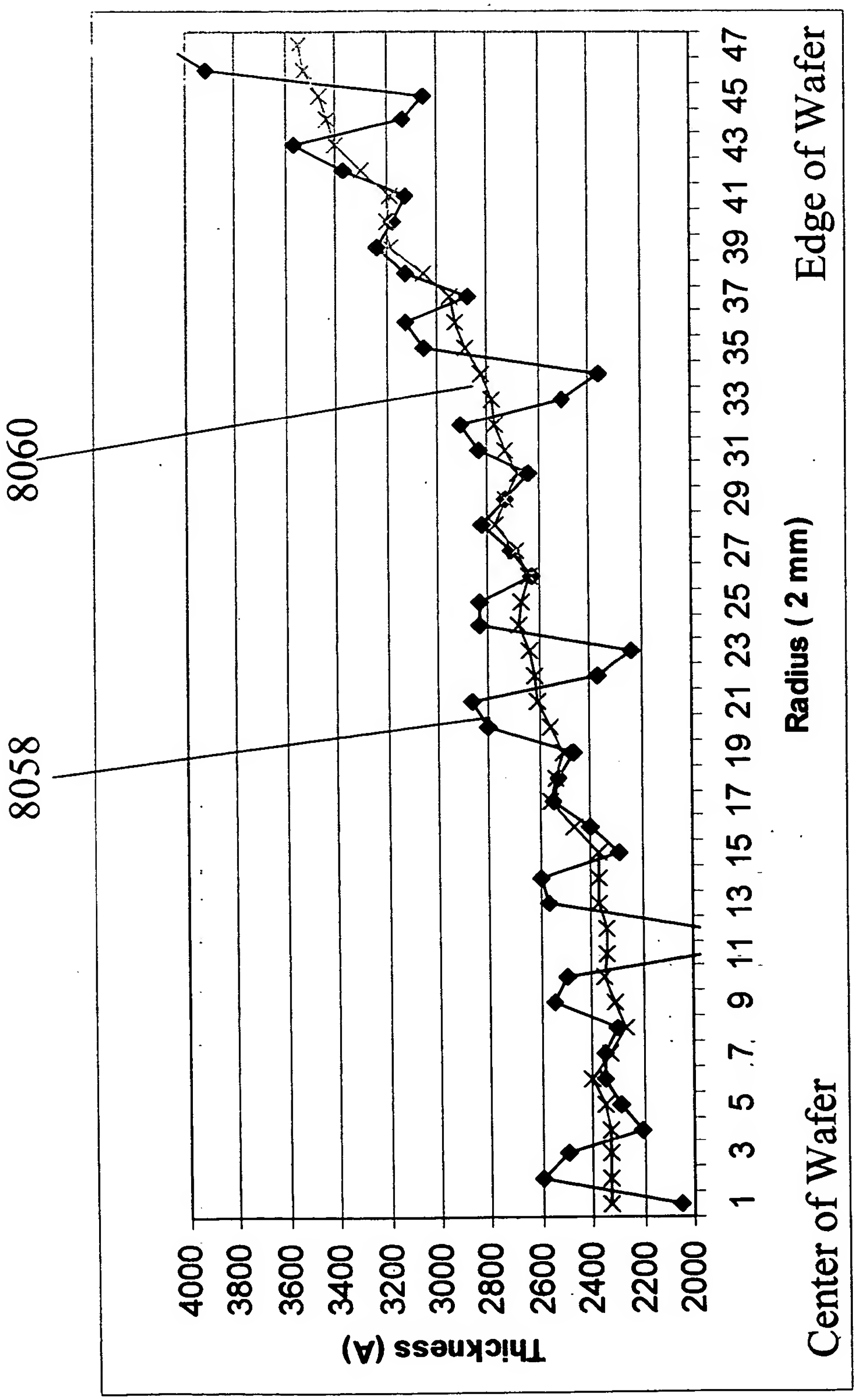
8058
8060
Thickness (A)
4000
3800
3600
3400
3200
3000
2800
2600
2400
2200
2000
1 3 5 7 9 11 13 15 17 19 21 23 25 27 29 31 33 35 37 39 41 43 45 47
Radius (2 mm)
Center of Wafer
Edge of Wafer

Fig. 8

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Inventor: **Hui WANG**
Filed: **Herewith**
Sheet **9 of 12**

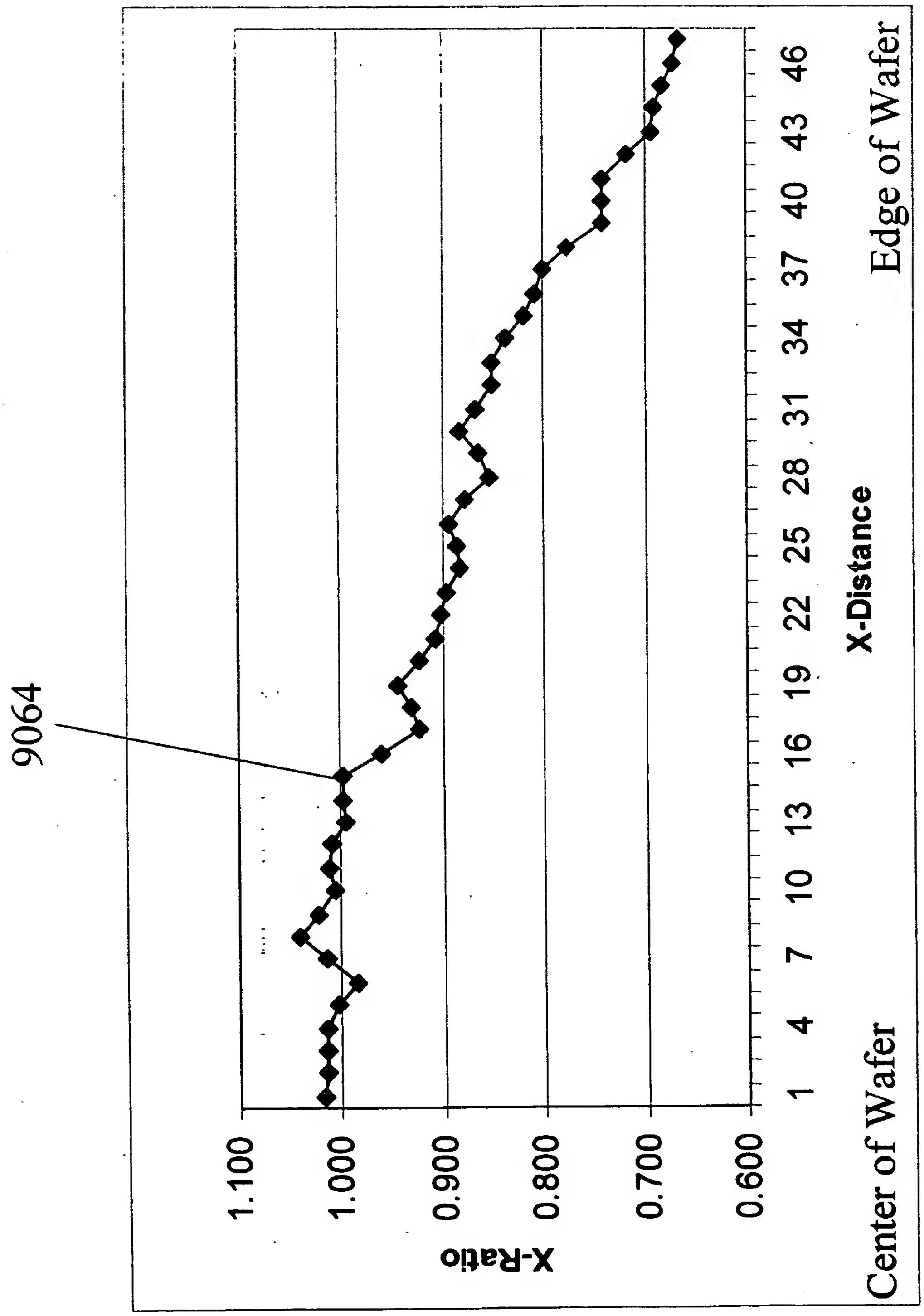

Fig. 9

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Inventor: Hui WANG
Filed: Herewith
Sheet 10 of 12

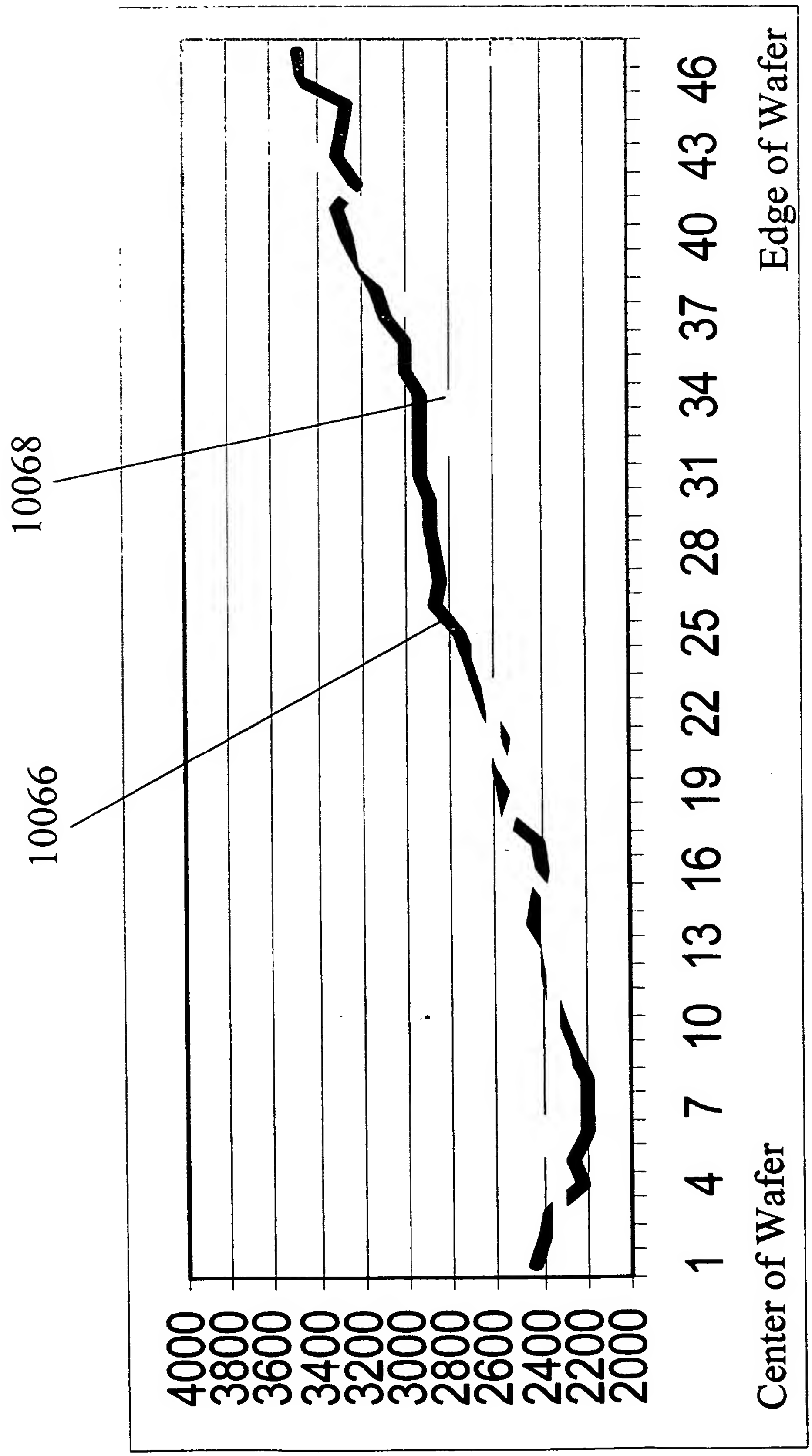

Fig. 10

Title: Methods for Reducing Residuals During Electropolishing
Inventor: Hui WANG
Filed: Herewith

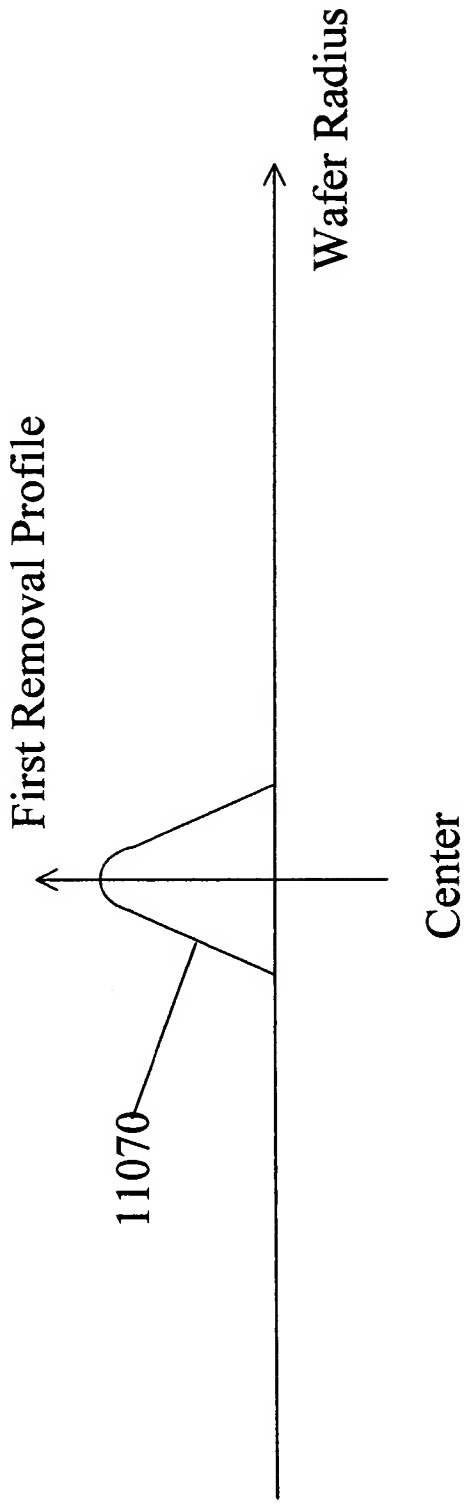

Fig. 11A

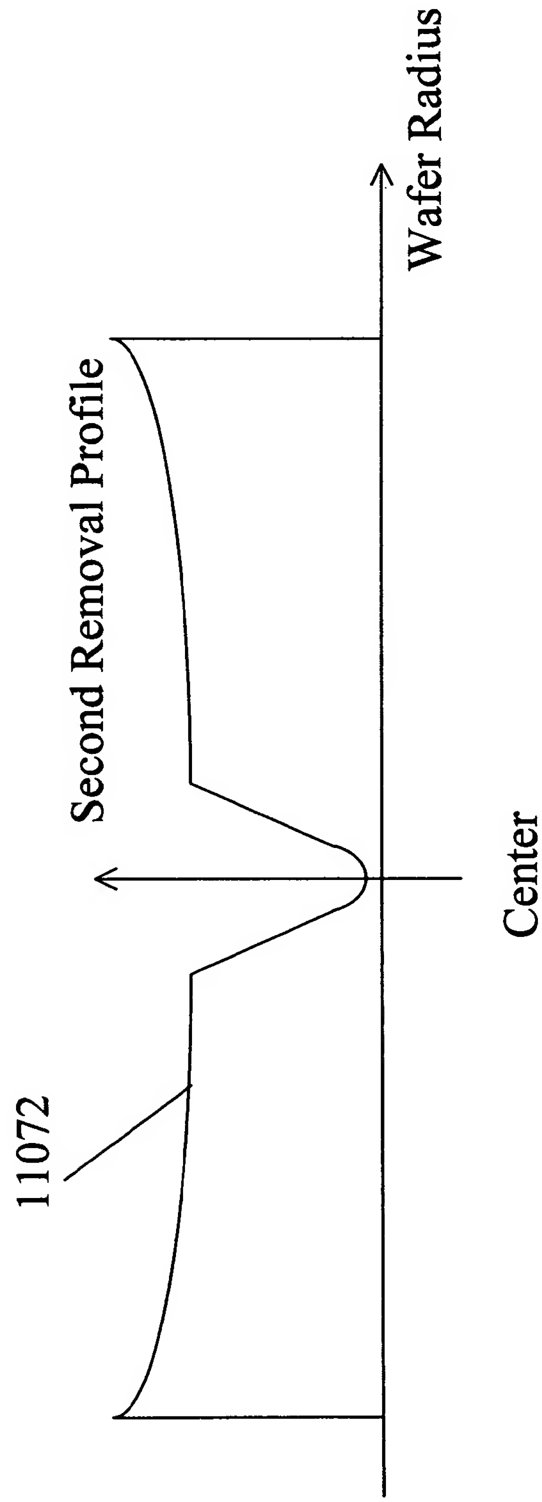

Fig. 11B

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Inventor: **Hui WANG**
Filed: **Herewith**

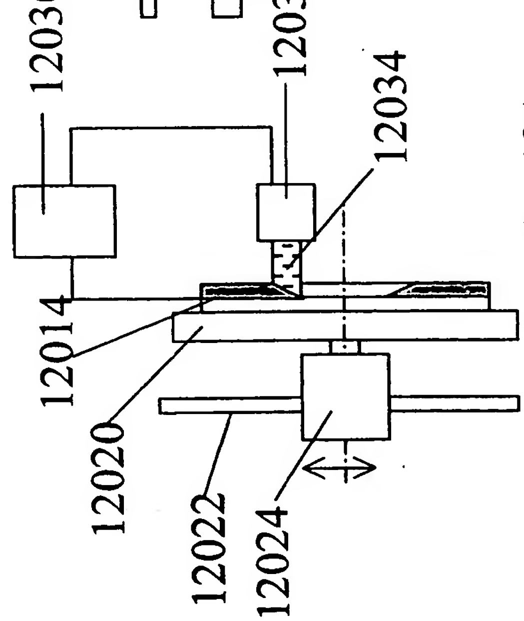

Fig. 12A

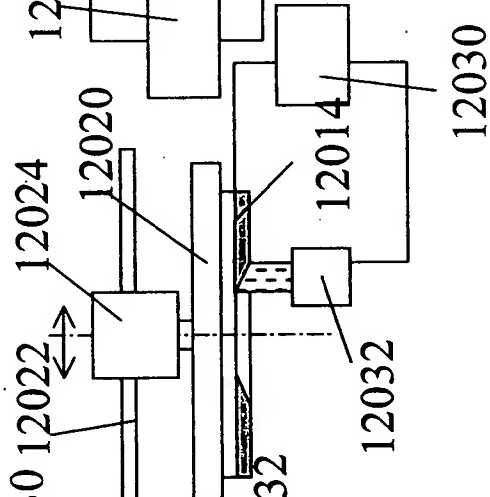

Fig. 12B

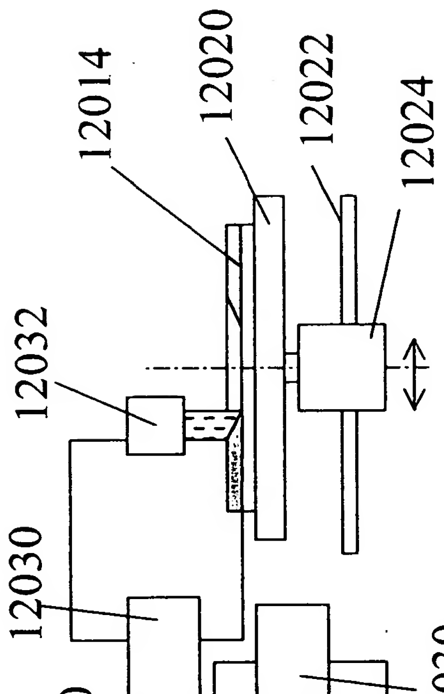

Fig. 12C

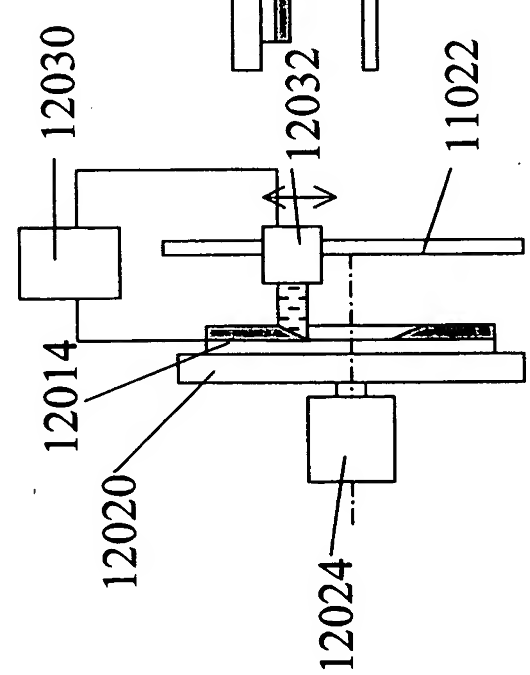

Fig. 12D

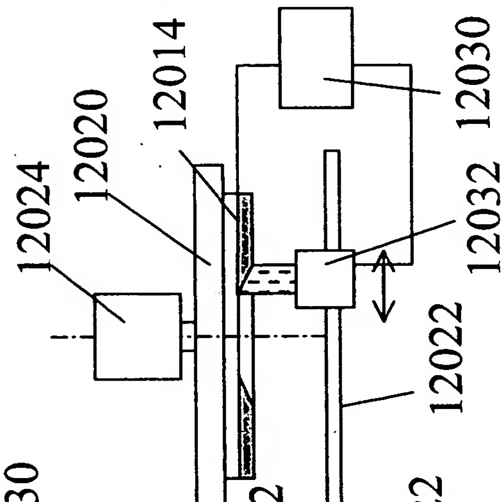

Fig. 12E

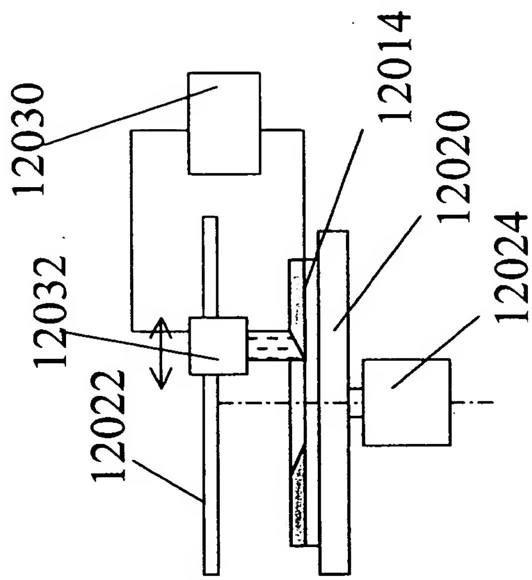

Fig. 12F

Application Data Sheet

Application Information

Application Type::	Provisional
Subject Matter::	Utility
Suggested classification::	
Suggested Group Art Unit::	
CD-ROM or CD-R?::	
Number of CD disks::	
Number of copies of CDs::	
Sequence submission?::	
Computer Readable Form (CRF)?::	
Number of copies of CRF::	
Title::	Methods For Reducing Residuals During Electropolishing
Attorney Docket Number::	
Request for Early Publication?::	
Request for Non-Publication?::	
Suggested Drawing Figure::	
Total Drawing Sheets::	12
Small Entity?::	Yes
Petition included?::	
Petition Type::	

Applicant Information

Applicant Authority Type::	Inventor
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Status::	Full Capacity
Given Name::	HUI
Middle Name::	
Family Name::	WANG
Name Suffix::	

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Representative Information

Representative Designation::	Registration number::	Name::
Primary	44417	Peter J. Yim

Domestic Priority Information

Application::	Continuity Type::	Parent Application::	Parent Filing Date::

Foreign Priority Information

Country::	Application number::	Filing Date::	Priority Claimed::

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